Near Shore Wave Processes

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LONG-TERM GOALS

Long-term goals are to predict the wave-induced three-dimensional velocity field and induced sediment transport over arbitrary bathymetry in the near shore given the offshore wave conditions.

SCIENTIFIC OBJECTIVES

We hypothesize that the wave-induced kinematic, sediment and morphologic processes are nonlinearly interrelated at the same space and time scales, so that it is necessary to measure all processes simultaneous over the water column to understand individual processes. The primary mechanism for changes in moment flux which drives the near shore dynamics is due to the dissipation of breaking waves, the processes of which are only poorly understood. To improve our understanding of breaking waves, the dissipation associated with bubble injection is measured along with the velocity fields over the vertical. Bottom boundary layer measurements are obtained to determine bottom stress and dissipation. Sediment transport is measured in response to the measured mean longshore and cross-shore currents, wave velocities and induced stresses. The small-scale morphology, which acts as hydraulic roughness for the mean flows and perturbs the velocity-sediment fields, is measured as a function of time and over large areas to examine cross-shore and alongshore variation.

APPROACH

Vertical distributions throughout the water column of 3-component mean, wave-induced and turbulent velocities, bubbles, sediment concentrations are measured from an instrumented sled. The 3-component velocity field is measured every 5 cm over the bottom 1 m with a downward looking 1.3 MHz bistatic coherent acoustic Doppler velocimeter, BCDV, (1.7 cm bin size at 48 Hz) and in the upper water column with a 300 KHz upward looking coherent bistatic acoustic Doppler velocimeter every 8 cm (8 cm bin size at 10 Hz). The BCDV also infers the vertical profile of suspended sediment concentration every 1.7 cm over the bottom 1m from the acoustic backscatter intensity. In addition, the vertical distribution of the horizontal velocities are measured with an array of 8 electromagnetic current meters. A 2 m cross-shore array of six optical backscatter instruments measures the horizontal coherence length scale and advection. The small-scale morphology is measured with an array of 7 sonic altimeters mounted on the back of the CRAB, and from the sled with a newly developed, in-

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house, x-y scanning altimeter. Bubble injection and depth of bubble penetration are measured with the two acoustic systems (1.3 MHz looking down and 300KHz looking up), and with a 3 m vertical array of 8 conductivity cells. An important component of the cross-shore sediment flux is due to the cross-shore mean flow (undertow), which is forced by wave set-up/down; the set-up is measured with a cross-shore array of 8 pressure sensors. Set-up is an integral measure of the turbulent Reynold's stresses and wave radiation stresses and acts as a check for the detailed velocity measurements. The local sled measurements are placed in synoptic perspective using the continuously recording cross-shore array of pressure sensors to measure wave transformation and set-up, along with the current/wave sensor array of Elgar and Guza.

The SandyDuck measurements described above are the basis of our modeling and analysis work. The analyses are identified as separate, but interrelated topics to describe wave, current, sediment and morphology processes over both the vertical and cross-shore.

WORK COMPLETED

We participated in the SandyDuck nearshore experiment conducted at the U.S. Army Field Research Facility, Duck North Carolina. Measurements were obtained throughout the 6-week intensive measurement period from 22 September to 31 October 1997. The bottom profile during this period consisted on a well-defined outer bar and very short inner bar, bar terrace or at times no bar, which was unanticipated in the experimental design. The waves were unusually mild during this period, with only one major storm. Data were acquired using sensors mounted on a movable sled, arrays of fixed instruments, and altimeters mounted on the moving CRAB (Figure 1). The mobile sled allowed adapting to the profile, and advantage was taken of the milder wave conditions to study wave boundary layers in deeper water simulating waves on the inner shelf. Our measurements during SandyDuck were focused on comprehensively describing the velocity field, sediment transport and morphology over the entire water column with emphasis on surface and bottom boundary layers. The experiment was designed to test quasi-3D hydrodynamic/sediment transport models.

RESULTS

An example of vertical profiles of mean currents, bubbles (void fraction), turbulent kinetic energy, bottom dissipation and sediment concentration along with the small-scale morphology during the SandyDuck experiment are shown in Figure 2. The measurements were made on the outer surf zone. The mean longshore current bottom boundary layer is well described by a logarithmic profile. The onshore mass transport velocity is calculated taking the instruments coming in and out of the water into account. The bubbles in the water column measured as a void fraction are well described as an exponential decay relative the instantaneous water surface. The turbulent kinetic energy scales with distance from the bottom. Dissipation is maximum near the bed as is sediment concentration. The bottom morphology is composed of megaripples O(1-2 m wavelength) oriented parallel to shore.

The cross-shore distributions of mean longshore currents observed during the DUCK94 experiment were compared with predictions of a quasi three-dimensional near shore circulation mode (Faria,

Figure 1. Instrumented sled (conductivity array on right tower, em current meter array on left tower, BCDV mounted on hydraulically controlled boom at back left) being pulled offshore with instrumented CRAB (acoustic altimeter array along back).

Thornton, Stanton, Lippmann, Guza, and Elgar, 1998). The model includes forcing due to breaking waves described using the roller concept (Lippmann and Thornton, 1997), alongshore wind stress, cross-shore advection of mean momentum of the alongshore current, and a full non linear bottom shear stress with a variable bed shear stress coefficient, Cf, constrained by observations. Contributions from the alongshore wind stress are mostly evident offshore and over the inner trough of the sand bar due to the relative increase in the wind force to wave force ratio as wave forcing decreases over these regions. The advection of the momentum of the longshore current by mean cross-shore currents is shown to improve the agreement with observations within the surf zone, O[10 percent]. The use of a non linear bedshear stress formulation with a variable Cf is shown to improve model/data comparison, O[20 percent], compared to the use of a constant Cf. The largest overall improvement with observations is obtained by incorporating the roller stress contribution, O[50 percent].

The vertical profiles of undertow measured beneath the wave troughs were near uniform in the regions offshore of the primary breakers and in the inner trough. In terms of modeling, this would indicate that the forcing at these locations was near zero (or the vertical eddy viscosity was large). Strong shear in the vertical profiles of the undertow was found over the bar and on the foreshore. A jet was found over the bar and just inside the bar as a result of strong wave breaking compressing the vertical region of the undertow. Similar results were found during the Duck94 experiment at this same location (Faria, Thornton, Lippmann, and Stanton, 1998)
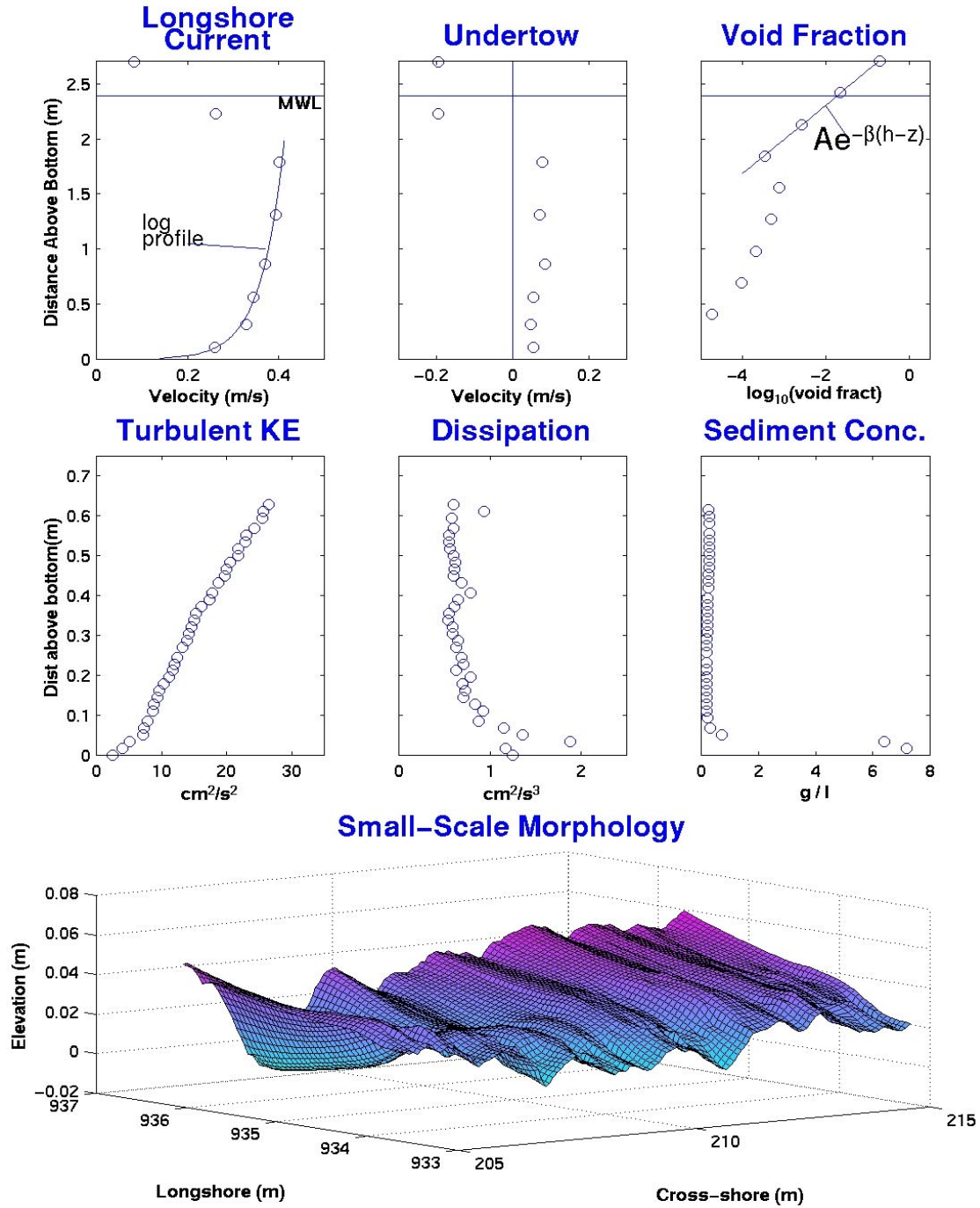
Figure 2. Vertical profiles of mean longshore and cross-shore (undertow) currents measured with em current meter array, bubble profile (void fraction) measured with conductivity array, turbulent kinetic energy (assuming isotropic turbulence), dissipation and sediment concentration measured with the BCDV. The small-scale morphology was measured with the array of altimeters from the back of the CRAB.

IMPACT/APPLICATION

The largest improvements for modeling of mean longshore currents compared with with data acquired during DUCK94, (using the simple Thornton and Guza (1986) formulation of balancing the radiation stress gradient with the bottom shear stress for comparison) was found to be: 1) O[50} percent improvement by incorporating a roller stress contribution (Lippmann and Thornton, 1997); 2) O[20} percent improvement by including a variable non linear bottom shear stress formulation; and 3) O[10] percent improvement by including the momentum mixing by the advection of the longshore current momentum by the mean cross-shore currents.

The alongshore pressure gradient is shown to be a first order forcing mechanism within the trough of the barred beach due to small perturbations in the seemingly homogeneous alongshore bathymetry during DELILAH. The pressure gradient results in the longshore current maximum being over the trough.

TRANSITIONS

The Bistatic Coherent Doppler Velocimeter (BCDV) developed under this project will be used in the Wave Shoaling DRI to measure wave dissipation due to bottom friction and small-scale morphology. The scanning x-y altimeter was developed under Shoaling Waves DRI funding and used successfully at SANDYDUCK.

Work is under way to transition the modeling results to a fully integrated quasi-3D nearshore dynamics model.

RELATED PROJECTS

1. Collaborative modeling of a turbulent wave boundary layer perturbed by an undulating bottom is being performed by Paulo Blondeaux and Giovanna Vittori from the University of Genoa and Enrico Foti from the University of Catania through a NICOP program.

2. Collaborative modeling of longshore and cross-shore currents is being performed by Ad Reniers and Frank Wiersma, Delft University, through MAST and NICOP programs.

3. Collaborative modeling and data comparisons of breaking waves using Boussinesq equations is being performed by PhD students at the U of Quebec under co-direction of Barbara Boczar-Karakiewicz and myself.

4. Analysis of SandyDuck data is being performed in collaboration with SandyDuck investigators Tom Lippmann, Bob Guza, Steve Elgar, Chuck Long and Bill Birkemeier.

5. Much of the instrumentation developed and procured under this program will be utilized in the Wave Shoaling DRI experiment, Sep-Dec 1999 also at Duck, NC.

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